Comparison of Telemedicine Screening of Diabetic Retinopathy by Mydriatic Smartphone-Based vs Nonmydriatic Tabletop Camera-Based Fundus Imaging

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Abstract

Purpose: To compare dilated smartphone-based imaging with a nonmydriatic, tabletop fundus camera as a teleophthalmology screening tool for diabetic retinopathy (DR). **Methods:** This was a single-institutional, cross-sectional, comparative-instrument study. Fifty-six patients at a safety-net hospital underwent teleophthalmology screening for DR using standard, nonmydriatic fundus photography with a tabletop camera (Nidek NM-1000) and dilated fundus photography using a smartphone camera with lens adapter (Paxos Scope, Verana Health). Masked graders performed standardized photo grading. Quantitative comparisons were performed employing descriptive, κ , Bland-Altman, and receiver operating characteristic analyses. **Results:** Posterior segment photography was of sufficient quality to grade in 89% of mydriatic smartphone-imaged eyes and in 86% of nonmydriatic tabletop camera-imaged eyes ($P = .03$). Using the tabletop camera as the reference to detect moderate nonproliferative DR or worse (referral-warranted DR), mydriatic smartphone-acquired photographs were found to be 82% sensitive and 96% specific. Dilated smartphone imaging detected referral-warranted DR in 3 eyes whose tabletop camera imaging did not demonstrate referral-warranted DR. Secondary masked review of medical records for the discordances in referral-warranted status from the two imaging modalities was performed, and it revealed revised sensitivity and specificity values of 95% and 98%, respectively. Overall, there was good agreement between tabletop camera and smartphone-acquired photo grades ($\kappa = 0.91 \pm 0.1, P < .001$; area under the receiver operating characteristic curve = 0.99, 95% CI, 0.98-1.00). **Conclusions:** Mydriatic smartphone-based imaging resulted in fewer ungradable photos compared to nonmydriatic table-top camera imaging and detected more patients with referral-warranted DR. Our study supports the use of mydriatic smartphone teleophthalmology as an alternative method to screen for DR.

Keywords

diabetic retinopathy, fundus photography, nonmydriatic camera, screening, smartphone, telemedicine

Introduction

In the United States, approximately 30.3 million people are currently affected by diabetes, and the incidence of newly diagnosed diabetes in adults aged 18 years or older is estimated to be 1.5 million every year.¹ Diabetic retinopathy (DR) and diabetic macular edema are common ophthalmic sequelae of diabetes that result from variable degrees of retinal capillary hyperpermeability and nonperfusion. DR is the leading cause of blindness in adults in the United States, and the prevalence of DR among patients with diabetes has been estimated to be 27.7%.²

If detected and treated promptly, blindness from DR can be mitigated.³ However, rates of screening for DR remain low, with adherence to retinal screening guidelines established by the American Diabetes Association estimated to

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be as low as 29% to 49%.⁴ The screening rates are particularly low in the health care safety-net setting, perhaps related to insufficient provider availability, cost to the patient, and poor access to care.^{4,5}

The use of single-field, nonmydriatic, digital fundus photography in telemedicine has become a standard screening tool for DR and has been demonstrated to increase diabetic eye examination rates across a variety of practice settings, from underserved communities to hospital centers.⁶⁻¹⁰ A randomized trial of screening for DR in a rural primary care clinic using this method produced a 6-fold increase in the rate of retinal examination compared with a system in which patients were referred to an ophthalmologist.¹⁰ However, these tabletop fundus cameras are expensive, ranging in cost from several thousand dollars to more than \$20,000 each, and issues of portability and convenience persist in the primary care setting.

Smartphones provide a more portable platform to measure near visual acuity (VA) and to capture external, anterior segment, and fundus photographs.¹¹⁻¹³ A comparative study by Russo et al¹⁴ on the use of mydriatic direct ophthalmoscopy through a smartphone-coupled imaging device found considerable agreement with dilated slitlamp biomicroscopy for the grading of DR. Ryan et al¹⁵ showed that the sensitivity and specificity of manual, mydriatic smartphone fundus photography compared with nonmydriatic fundus photography for the detection of DR were 81% and 94%, respectively, in a study of a diabetic population in Chennai, India. That study used manual, dilated smartphone fundus photography in which a 20-diopter lens was held in one hand and a smartphone in the other, with the smartphone flash serving as the illumination source.

We previously demonstrated the efficacy of mydriatic smartphone-based diabetic eye screening by comparing a commercial, smartphone-coupled indirect ophthalmoscopy camera system (Paxos Scope, Verana Health, previously Digi-Sight Technologies, Inc.) with standard in-clinic examination for referral-warranted DR.¹⁶ The device used an adjustable, external light-emitting diode light source for indirect ophthalmoscopy rather than the smartphone's internal light source. In the present study, we compared the efficacy of this device with a nonmydriatic tabletop camera in the same clinical safety-net setting.

At the time of this study, more than 30 000 patients were receiving clinical care for diabetes at Santa Clara Valley Medical Center (SCVMC) (San Jose, CA), which predominantly serves uninsured and medically underserved patients and has a reported prevalence of 30.3% of DR or diabetic macular edema.¹⁷ Improving access to screening for DR is important in this population because of the limited access to ophthalmic care experienced by many of these patients. The present study compared the effectiveness of a portable mydriatic smartphone-based telemedicine system to that of single-field, digital, nonmydriatic, tabletop fundus photography in the screening of DR at the SCVMC Diabetes Clinic, with the aim of providing further evidence supporting the use of this

platform, particularly in areas where access to retinal screening may be limited.

Methods

Patient Enrollment

This was a prospective, single-institutional, comparative series of 112 eyes from 56 patients comparing the utility of a single-field, nonmydriatic fundus photograph acquired using a tabletop camera to that of a fundus photograph obtained after pupillary dilation from a smartphone camera for ophthalmic screening of diabetic eye disease using a store-and-forward telemedicine method. Participants in the study were consecutively recruited from March 2015 to June 2015 for a single-visit evaluation by 2 methods of telemedicine screening performed in parallel. Participants enrolled were a subset of patients who presented to the SCVMC Diabetes Clinic for DR screening by nonmydriatic tabletop fundus camera photography. Patients were referred for screening by their primary care provider or the SCVMC Diabetes Clinic. As such, adult patients with a diagnosis of diabetes were included in the study.

Photograph Acquisition

Both eyes of all participants underwent standard single-field fundus photography captured by a trained medical assistant with a Nidek NM-1000 nonmydriatic tabletop fundus camera, which acquired a single, nonmydriatic 45°-field-of-view fundus image centered on the macula. Concurrently, patients underwent mydriatic smartphone-assisted acquisition of spectacle-corrected near VA and anterior/posterior segment photography. Photographs for both imaging modalities were acquired in the same examination room with equally dim lighting conditions. The acquisition of near VA was patient self-administered and involved forced multiple choice, single-letter discrimination on a high-contrast background at 14 inches, as previously described.¹⁸ The smartphone-assisted acquisition of a fundus photograph relied on an iPhone 5s (Apple Inc) camera phone (8 megapixel resolution), Paxos Scope (Figure 1; described in detail previously^{19,20} and registered with the Food and Drug Administration as a Class II 510[k]-exempt device) with anterior and posterior segment hardware adapters and external light-emitting diode illumination, and a beta version of the Paxos Scope mobile application, previously SightBook (Verana Health).

The acquisition of mydriatic smartphone-assisted fundus photography was performed by a trained medical student (M.P.) using the following methodology: Both eyes of all patients were dilated with 1 drop each of 2.5% phenylephrine and 1% tropicamide after VA measurement. Anterior segment photography was performed using an anterior segment adapter before and after pharmacologic dilation.²⁰ The adapter, which contained a macro lens and an external light source, was attached to the phone. The patient was instructed to fixate on a target straight ahead with eyes wide open while the phone,

Figure 1. Paxos Scope telemedicine device with posterior segment adapter. The iPhone 5s (Apple Inc) with external light-emitting diode illumination was attached to the Paxos Scope posterior segment adapter (Stanford University), which was fitted with a Digital ClearField indirect ophthalmoscopy lens (Volk Optical Inc) as shown.

held in landscape orientation, was brought directly to within 2 inches of the patient's orbital rim until the pupillary margin of the iris was in focus.

Fundus photography was then performed using a Volk Digital ClearField lens (Volk Optical Inc) mounted on the posterior segment adapter to capture views that included the optic nerve and macula spanning approximately 45°. To accomplish this, the anterior segment adapter with integrated light and the posterior segment adapter that held the indirect lens were attached to the phone. Similarly to indirect ophthalmoscopy, the patient was instructed to fixate straight ahead while the phone-adapter complex was stabilized with fingers braced on the patient's brow and cheek, and with the axis between the indirect lens and camera directed nasally toward the optic nerve. Once the optic nerve was adequately in focus, the view was tilted temporally to obtain a broader view of the posterior pole.

VA data and participant photographs were automatically uploaded to a secure, Health Insurance Portability and Accountability Act (HIPAA)–, cloud-based server (www.digi-sight.net) at the time of the visit to use for remote grading with a store-and-forward telemedicine method.

Photograph Grading and Statistical Analysis

Visual acuities were converted from near Snellen-equivalent to Early Treatment of Diabetic Retinopathy Study (ETDRS) letters for analysis.²¹ Anterior segment photographs obtained through the smartphone platform were evaluated for their quality. The presence or absence of iris neovascularization, cataract, and corneal opacity was also recorded. Posterior segment photographs from the smartphone platform were graded for photograph quality and the severity of DR (none, mild nonproliferative diabetic retinopathy [NPDR], moderate NPDR, severe NPDR, PDR, or unable to grade) by 2 masked graders (C.P. and L.L.) based on the International Clinical Classification for Diabetic Retinopathy disease severity scale.²² In cases where there was a disagreement between the 2 graders on photograph quality or severity of DR, a third masked grader (M.S.B.) adjudicated a final grade.

Table 1. Participant Demographics.

Characteristic	Value
No. of patients (eyes)	112 (112)
Age, mean $\pm$ SD, y	60 $\pm$ 12.5
Female sex, %	53
Duration of diabetes, mean $\pm$ SD, y	10 $\pm$ 8.3
Race, %	
White	15
Latino	49
Asian	24
African American	7
Other	5
Visual acuity	
Mean, Snellen (mean $\pm$ SD, ETDRS letters)	20/50 (66 $\pm$ 16)
Median, Snellen (median, IQR, ETDRS letters)	20/40 (70, 65-80)

Abbreviations: ETDRS, Early Treatment of Diabetic Retinopathy Study; IQR, interquartile range.

Referral-warranted DR was defined as moderate NPDR or worse,²³ and secondary masked review of dilated fundus examination documentation in the electronic medical record was performed in cases of discordance for referral-warranted disease between the 2 imaging modalities. The number of photographs taken to ensure a quality sufficient for grading was also recorded for both acquisition methods. The quality of each photograph was graded on a 4-point scale (0 = poor, if unable to evaluate reliably; 1 = fair, if out of focus or presence of shadow; 2 = good, if able to see fovea; 3 = excellent, if fovea in excellent focus).

Statistical analysis comparing the nonmydriatic tabletop camera to mydriatic smartphone-acquired data was performed using Stata 14 (StataCorp) to calculate descriptive, κ , Bland-Altman, and receiver operating characteristic analyses. Analyses were clustered by patient to account for the correlation between fellow eyes of a single patient.

Results

Demographics

Table 1 displays demographic data for the 112 individuals enrolled in this study. The participants had a mean age of 60 $\pm$ 12.5 years and a mean duration of diabetes of 10 $\pm$ 8.3 years. The racial composition of the participants was 49% Latino, 24% Asian, 15% White, 7% African American, and 5% other race.

Visual Acuity

The mean near spectacle-corrected VA measured by the smartphone application was 20/50 (66 $\pm$ 16 ETDRS letters). The median Snellen VA was 20/40 (70; interquartile range, 65-80, ETDRS letters).

Figure 2. Examples of dilated fundus smartphone photographs and corresponding nonmydriatic tabletop camera photographs. (A) Mydriatic smartphone photograph of eye with no diabetic retinopathy. (B) Nonmydriatic photograph of same eye. (C) Mydriatic smartphone photograph of mild nonproliferative diabetic retinopathy (NPDR). (D) Nonmydriatic photograph of mild NPDR. (E and F) Mydriatic smartphone photographs of moderate NPDR. (G) Nonmydriatic photograph of moderate NPDR. (H and I) Mydriatic smartphone photographs of severe NPDR. (J) Nonmydriatic photograph of severe NPDR. (K and L) Mydriatic smartphone photographs of PDR. (M) Nonmydriatic photograph of PDR.

Photograph Quality

A total of 111 anterior segment photographs were deemed to be of sufficient quality (eyelids open and image focused on the iris) to evaluate for neovascularization of the iris.

Figure 2 demonstrates a side-by-side comparison of posterior segment photographs captured by the 2 cameras and presented for grading. For each patient, only 1 photograph of the posterior segment was taken with the nonmydriatic tabletop camera. For the mydriatic smartphone-based photograph, an average of 2 ± 0.9 photographs were taken. The average quality of smartphone and tabletop camera photographs were 1.8 ± 0.09 and 1.9 ± 0.1 , respectively. Sixteen eyes (14%) had ungradable posterior photographs by the nonmydriatic camera, whereas 12 eyes (11%) had ungradable posterior photographs by the mydriatic smartphone-based system. This difference was statistically significant ($P = .03$, McNemar χ^2 test). The most common causes for decreased posterior segment photograph quality included media opacity (cataract) and poor dilation.

Anterior Segment Grading

Anterior segment photographs were graded by 1 masked reviewer (B.C.T.). One eye was found to have neovascularization of the iris. Other pertinent anterior segment findings included cataract (3 eyes), iris atrophy (1 eye), glaucoma

drainage device (1 eye), peripheral iridotomy (1 eye), and posterior embryotoxon (1 eye).

Posterior Segment Grading

Fundus photographs were graded by 2 masked reviewers (C.P. and L.L.) and scored on a 6-point scale: no retinopathy, mild NPDR, moderate NPDR, severe NPDR, PDR, and unable to grade. Consensus between the 2 reviewers was good: 90% agreement for the tabletop camera photographs ($\kappa = 0.75$) and 92% agreement for the smartphone-based photographs ($\kappa = 0.81$). When the photograph grade assigned by the 2 masked reviewers differed, a third masked reviewer (M.S.B.) adjudicated the final photograph grade. This was necessary in 2 tabletop camera and 7 smartphone images.

Table 2 is a frequency table that compares the grades of retinopathy for photographs obtained from the smartphone and the tabletop camera. We examined the images from 7 patients for whom there was disagreement on the determination of referral-warranted disease between the 2 modalities. Four nonmydriatic tabletop camera images were deemed ungradable; the same eyes on mydriatic smartphone imaging were found to have gradable photographs: 3 were found to have no retinopathy, and 1 had PDR (Figure 3, A-H).

One patient who was found to be referable with moderate NPDR based on nonmydriatic tabletop camera imaging was found to have only mild NPDR on mydriatic smartphone

Table 2. Comparison of Diabetic Retinopathy Grading.^a

		Grade of retinopathy (mydriatic smartphone) ^c						Total
		None	Mild	Mod	Severe	PDR	U	
Grade of retinopathy (nonmydriatic Tabletop camera) ^c	None	74	7	1 ^b	0	0	0	82
	Mild	4	2	2 ^b	0	0	0	8
	Mod	0	1 ^b	2	0	0	0	3
	Severe	0	0	2	0	0	0	2
	PDR	0	0	0	0	1	0	1
	U	3 ^b	0	0	0	1	12	16
	Total	81	10	7	0	2	12	112

Abbreviations: Mod, moderate; PDR, proliferative diabetic retinopathy; U, ungradable.

^aFrequency table comparing the grade of diabetic retinopathy as ascertained by nonmydriatic tabletop fundus camera and mydriatic smartphone photograph. $\kappa = 0.58 \pm 0.06$ ($P < .001$). Sixteen photographs were ungradable mostly because of media opacity or poor dilation.

^bIndicates the 7 cases with discordant referral-warranted status that underwent secondary adjudication by documented clinical examination.

^cValues in bold indicate exact agreement.

Figure 3. Examples of 7 eyes whose nonmydriatic tabletop camera fundus photographs were deemed to be either ungradable or not referral-warranted, with corresponding mydriatic smartphone photographs. (A) Nonmydriatic photograph of patient 1. (B) Mydriatic smartphone photograph of same eye with no retinopathy. (C) Nonmydriatic photograph of patient 2. (D) Mydriatic smartphone photograph of same eye with no retinopathy. (E) Nonmydriatic photograph of patient 3. (F) Mydriatic smartphone photograph of eye of patient with proliferative diabetic retinopathy. (G) Nonmydriatic photograph of patient 4. (H) Mydriatic smartphone photograph of eye of patient with no retinopathy. (I) Nonmydriatic photograph of patient 5. (J) Mydriatic smartphone photograph of eye of patient with moderate nonproliferative diabetic retinopathy (NPDR). (K) Nonmydriatic photograph of diabetic retinopathy in patient 6. (L) Mydriatic smartphone photograph of eye of patient with moderate NPDR. (M) Nonmydriatic photograph of patient 7. (N) Mydriatic smartphone photographs of eye of patient with moderate NPDR.

Table 3. Comparison of Referral-Warranted Diabetic Retinopathy Grading.^a

		Mydriatic smartphone		
Nonmydriatic tabletop camera		No referral	Referral	Total
	No referral	90	2	92
	Referral	1	19	20
	Total	91	21	112

^aFrequency table comparing the grade of diabetic retinopathy as ascertained by nonmydriatic tabletop fundus camera and mydriatic smartphone photograph, dichotomized for referral if the grade of retinopathy was moderate nonproliferative diabetic retinopathy or worse, or if the photograph was ungradable. $\kappa = 0.91 \pm 0.09$ ($P < .001$).

imaging. Mydriatic smartphone imaging discovered 3 patients with referral-warranted disease (moderate NPDR) who were found by nonmydriatic tabletop camera imaging to have either no DR or mild NPDR (Figure 3, I-N). To resolve these discordances, masked review of documented clinical examinations in the electronic medical record were reviewed to assign a final reference grade (Supplemental Table).

Table 3 displays these data dichotomized into referral-warranted (moderate or severe NPDR, PDR, or unable to grade) and not referral-warranted (no retinopathy or mild NPDR) after secondary clinical adjudication for 7 patients whose photograph grades differed on referral-warranted status between the 2 imaging modalities. The κ value in this dichotomized analysis was 0.91, indicating good agreement between the smartphone-acquired and tabletop camera-acquired photograph grades. Using the nonmydriatic tabletop camera as the reference to detect referral-warranted DR, mydriatic smartphone-acquired photographs were found to be 82% sensitive and 96% specific, with a positive predictive value of 82% and a negative predictive value of 96%. After incorporation of a documented clinical examination reference, mydriatic smartphone-acquired photographs were found to be 95% sensitive and 98% specific, with a positive predictive value of 90% and a negative predictive value of 97%.

A Bland-Altman plot (Figure 4) demonstrated a bias near 0 and the 95% limits of agreement within -2 to $+1$ International Clinical Classification for Diabetic Retinopathy level for grading between the 2 methods. A receiver operating characteristic curve (Figure 5) demonstrates an area under the curve of 0.99 (95% CI, 0.98-1.00). Other incidental posterior segment findings included epiretinal membrane (3), peripapillary atrophy (1), and reticular degeneration (1).

Conclusions

Several studies have previously reported on the utility of fundus photography as part of a telemedicine approach to screen for DR.²⁴⁻²⁷ Although nonmydriatic tabletop fundus camera imaging remains the standard in teleretinal screening for diabetic eye disease, lack of portability and higher up-front equipment costs can often present challenges to widespread adoption, particularly in the low-resource settings where a large

Figure 4. Bland-Altman plot showing a bias near 0 and the 95% limits of agreement within -2 to $+1$ International Clinical Classification for Diabetic Retinopathy level for grading between the 2 methods. Nonmyd indicates nonmydriatic; Digi, smartphone.

Figure 5. Receiver operating characteristic curve demonstrating an area under the curve of 0.99 (95% CI, 0.98-1.00). ROC indicates receiver operating characteristic.

proportion of patients with diabetes receive care.^{6-10,28} The smartphone, in conjunction with pupillary dilation, offers a more portable and inexpensive alternative that can potentially increase screening in at-risk populations, and it is increasingly considered to be a reliable method of identifying referral-warranted DR.^{11,18}

We previously reported a study including 100 eyes from 50 adult patients with diabetes that had demonstrated good correlation between clinical Snellen and smartphone-acquired VA measurements ($\rho = 0.91$).¹⁶ In addition, smartphone-acquired dilated posterior photographs had demonstrated 91% sensitivity and 99% specificity compared with clinical examination in detecting referral-warranted DR, which was defined as moderate NPDR or worse. The decreased sensitivity (82%)

compared with the nonmydriatic tabletop camera in our initial analysis can be attributed to 3 eyes with ungradable photographs on tabletop camera imaging that were successfully imaged by smartphone after dilation and found to have no DR, as well as 3 eyes with referable DR findings on mydriatic smartphone imaging that were not detected on nonmydriatic tabletop camera imaging. Ensuing secondary masked review of medical records to determine the reference standard for the 7 total patients with discordant referral-warranted status revealed a sensitivity of 95%.

Several other studies support the use of mydriatic smartphone-based fundus photography as a reliable and cost-effective option to expand screening for DR.^{11,14-16,18,29,30} The prospective CAMRA (Comparison Among Methods of Retinopathy Assessment) study of 300 patients compared smartphone fundus photography after dilation and nonmydriatic fundus photography against reference standard 7-field mydriatic fundus photography in their ability to detect and grade DR.¹⁵ Tested in an outreach setting in India, detection of moderate NPDR or worse was comparable between mydriatic smartphone photography and nonmydriatic tabletop photography, with sensitivity of 59% (smartphone; 95% CI, 46%-72%) vs 54% (nonmydriatic; 95% CI, 40%-67%) and specificity of 100% (smartphone; 95% CI, 99%-100%) vs 99% (nonmydriatic; 95% CI, 98%-100%). Russo et al¹⁴ prospectively compared mydriatic smartphone-based direct ophthalmoscopy to dilated slitlamp examination in the detection of DR in 120 patients with type 1 or type 2 diabetes and found exact agreement in 204 of 240 eyes (85%, $\kappa = 0.78$; CI, 0.71-0.84). Moreover, the sensitivity and specificity of the smartphone-based method for detecting clinically significant macular edema were 81% and 98%, respectively.

Bilong and colleagues,²⁹ in a cross-sectional study of 220 patients with diabetes, compared the detection of DR using a smartphone attached to an adaptable camera device with pupillary dilation in a teleophthalmology setting with DR detection using indirect ophthalmoscopy, and found the sensitivity and specificity for all stages of DR to be 73.3% and 90.5%, respectively. The sensitivity and specificity improved to 80% and 99%, respectively, for severe NPDR and to 100% for both in PDR. Automation-assisted imaging with fixation guidance, multicolored illumination, and photomontage to generate 100° retinal photographs from 5 overlapping images obtained from a mydriatic smartphone-based system resulted in an average sensitivity of 93% and specificity of 56.8% in the detection of referral-warranted DR in a study of 71 patients with diabetes by Kim et al.³⁰

Despite nonmydriatic tabletop fundus imaging being standard community practice for DR screening, its use as the reference standard in our study had limitations. Factors such as media opacity and fixed imaging angle for the tabletop camera in the present study were significant examples. Applying a different reference standard, such as dilated tabletop fundus camera imaging, may have increased the reported sensitivity of mydriatic smartphone-based images to detect referral-warranted DR. We attempted to address this by reviewing

documented dilated fundus examinations within the medical records of patients for whom referral-warranted status was discordant between tabletop and smartphone images.

Mydriatic smartphone-assisted fundus photography in our study had relatively low rates of poor image quality, with 12 of 112 (11%) having ungradable images compared with 16 of 112 (14%) for the nonmydriatic camera, a difference that was statistically significant ($P = .03$). Most of these ungradable images were due to media opacity (such as cataract) or poor dilation, which are common limitations inherent to any tele-retinal screening. The smartphone's capability to acquire anterior segment photographs allows for the detection of certain media opacities that can explain poor image quality. This added function proved useful in our study when assessing ungradable images. Smartphone imaging was also better able to acquire gradable photographs through cataracts, likely because of pupillary dilation that allowed for image capture around lenticular opacities. In addition, the smartphone could be positioned at different angles during image capture, aiding its ability to bypass opacities to image the fundus. Other studies have reported even lower rates of poor image quality from the smartphone.^{14,15}

Limitations of the smartphone system include the need for pharmacologic dilation to obtain an adequate view of the posterior pole. Users who are not comfortable with dilating patients may thus be less inclined to use this method of fundus photography. Furthermore, patients who are unable to fixate consistently or stabilize their eye movements may present problems for obtaining adequate image quality. One of the limitations to our study is that it did not collect total acquisition times for fundus photographs and thus cannot report on timing differences between the 2 imaging modalities. An additional limitation to the use of the smartphone is that it may require some measure of technical skill with indirect ophthalmoscopy when capturing the posterior pole. However, our study employed a medical student without prior experience in indirect ophthalmoscopy, but who was trained over the course of 2 weeks for smartphone acquisition of photographs. Our results therefore suggest that a medical assistant without prior ophthalmic training, such as may be the case when operationalizing a telemedicine program, would not find the required technical skills to be prohibitive.

Our study reported on the use of a smartphone-based system to acquire near VA as well as nonmydriatic anterior segment and mydriatic posterior segment photographs in a community screening program. The photographs were remotely graded on the DigiSight Technologies (now Verana Health, Inc) secure web site (<https://www.digisight.net>). Graders logged in to view the photographs as they were uploaded and assigned varying grades of severity of DR. This platform has been used to extend the expertise of ophthalmologists to other low-resource settings.³¹ Future incorporation of artificial intelligence in the interpretation of fundus photographs acquired by smartphones may eliminate the need for graders, expand screening for at-risk populations, and provide faster results.

In summary, mydriatic smartphone-acquisition of fundus photographs offers a viable option for teleretinal screening of DR. The smartphone system offers unique advantages thanks to being portable, readily available, and convenient. These qualities make the device an especially attractive option for practice settings where the cost of a tabletop camera could be prohibitive and where resources for technician support are scarce. Future technical advances will likely continue to make the smartphone an increasingly reliable alternative to nonmydriatic cameras for the screening and grading of vision-threatening DR.

Authors' Notes

Dr Brian Chiwing Toy is now an assistant professor at the University of Southern California (USC) Roski Eye Institute, Department of Ophthalmology, Keck School of Medicine, USC, Los Angeles, California. This work was presented at the American Academy of Ophthalmology Annual Meeting, November 2015, in Las Vegas, Nevada.

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Ethical Approval

This study was conducted in accordance with the Declaration of Helsinki. The collection and evaluation of all protected patient health information was performed in a HIPAA-compliant manner. Ethical approval was obtained from the SCVMC Institutional Review Board (reference 14-002).

Statement of Informed Consent

Written informed consent, including permission for publication of deidentified patient information, photographs, and images included herein, was obtained from all participants before the study.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Mark Scott Blumenkranz is a member of the board of directors of Verana Health, Inc (formerly DigiSight Technologies, Inc). David Myung is a coinventor of the Paxos Scope ophthalmic camera system.

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Supplemental Material

Supplemental material is available online with this article.

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